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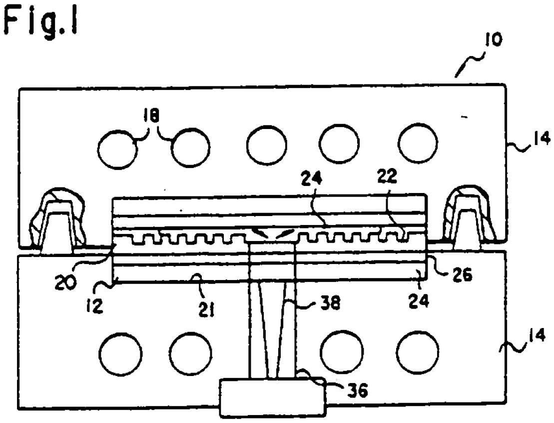
(54) Insulated mold structure for injection molding of optical disks.

(57) An insulated mold insert (12) is provided for injection molding compact disks and optical disks. The mold insert (12) is removably located in the mold cavity behind the stamper (20). The mold insert (12) has an insulation layer (24) retaining heat at the molding surface, thereby increasing surface smoothness of the molded part. The insert (12) may have a metal surface for contacting the back side of the stamper (20).

Fig.1



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tions on residual retardation or optical path difference) are also crucial factors to be considered in connection with optical disk manufacture.

Retardation Γ is defined as:

$$\Gamma - R\lambda \quad (1)$$

Where R is phase retardation and λ is the wave length of the source.

Birefringence, Δn, is then defined as:

$$\Delta n - \frac{R\lambda}{t} \quad (2)$$

Where t is the thickness of the optical medium. Thus, birefringence is a dimensionless quantity.

Birefringence is a net effect through a sample, which is predominately molten at the cessation of flow. Thus, molecular orientation in the quenched skins and slowly cooled core have a direct effect on the retardation. Molecular orientation is proportional to the applied stress field creating the flow which is related to birefringence, according to the following expression:

$$\Delta n_{13} - (n_{11} - n_{33}) - C(\sigma_{11} - \sigma_{33}) \quad (3)$$

for a simple shear flow where C is the stress-optical coefficient. This analysis can be taken a step further by relating the normal stress difference $(\sigma_{11}\text{-}\sigma_{33})$ to the shear stress, σ_{12}, as follows:

$$(\sigma_{11} - \sigma_{33}) \propto \sigma^2_{12} \quad (4)$$

Hence, substituting equation (4) into equation (3) gives

$$(n_{11} - n_{33}) - K\sigma^2_{12} \quad (5)$$

where K is a constant and n_{11} and n_{33} are the refractive indices in the flow and cross-flow directions, respectively. The expression is valid for polystyrene melts and for low molecular weight polycarbonate. In an optical disk, the flow originates at the center of the disk and radially diverges towards the outer edges as the melt fills the cavity. Hence, rendering the birefringence profile uniform in a diverging radial flow field is not a simple task. Molecular orientation varies radially as the flow front speed (and wall shear stress) decreases.

The phase retardation, Γ, is usually expressed in terms of nanometers (10^{-9} meters). Since CD's are nominally 1.2mm thick, retardation is typically specified, rather than birefringence, and retardation will be used where appropriate in the discussion below.

Retardation may be measured with a commercial instrument marketed by Hinds International. The instrument is a system consisting of a 2mW He-Ne laser (λ-632.8 nm), photoelastic modulator and lock-in amplifier. The output is stored in a Nicolet storage scope and then may be transferred to a floppy disk or x-y plotter. The wavelength of the He-Ne laser in the analyzer is 632.8nm. This may be adjusted to λ-780nm as a reference and the output multiplied by 2 for double pass values.

A typical retardation profile is minimal at the hub and outer edge and is maximum at the midpoint of the annular disk area. The difference between the maximum and minimum is $\Delta\Gamma$. To measure the profile, the disk is rotated in a direction perpendicular to the incident light which passes along a radial path from the outer edge to the hub. The rotating disk is then withdrawn along the same path resulting in a second measurement on the same disk. The maximum and minimum retardation may then be noted as well as the absolute difference $\Delta\Gamma$. The extreme ends, i.e., outer edge and hub, of the retardation signal may be ignored because they do not contain recorded information.

The definitive test of a compact disk is the audio quality when played by a CD player. Assuming good aluminum film deposition and a good stamper, the accuracy of the encoded digital information is a function of the optical properties of the substrate and the pits replication of the stamper from which it is pressed.

Requirements for optical storage media are much more stringent than those specified for CD's. Normal retardation is reduced to ±20nm and off-axis retardation (30° off normal) must be below ±70nm. A good birefringence profile is nearly isotropic. Both normal and off-axis measurements have relatively low, acceptable levels of retardation. In addition, the optical properties at each radial position should be as uniform as possible.

The interrelationship of process conditions, birefringence and pit replication is highly complex when manufacturing digital audio disks. The retardation profiles are a reliable measure of the effect which process conditions have on final optical properties. Circumferential variations reflect non-uniform heat transfer in the mold. Also, because the polycarbonate must cool against the nickel stamper with precise molding of the pits, heat transfer, here too, is important. Thus, improvement is required to render the heat transfer more uniform or at least more symmetrical about the central sprue.

SUMMARY OF THE INVENTION

The present invention is based upon the discovery that an insulated mold insert may be employed to manufacture high quality media disks, such as, optical disks, compact disks, and computer disks, having improved uniformity of birefringence and improved surface quality.

In one embodiment of the present invention, the insert backs up a mold surface or stamper employed for producing disks in an injection molding or injection compression molding apparatus. The insert comprises a structure including an insulation layer and optionally a hard, conductive skin layer. The insert has a free surface adapted to be in thermal contact with the rear of the mold surface. The thermal characteristics of the mold insert result in improved pits replication, reduced residual stress and orientation resulting in more uniform birefringence.

The invention also is directed to a method for

In addition, the surface 31 of the skin layer 26 may be finished to an optical quality for abutment with the rear surface of the stamper 20 to effect good pits replication.

The skin layer 26 may be fabricated from other materials including carbon steel, stainless steel, nickel, aluminum, brass, copper, ceramics, glass, quartz, electrodeposited and electroless metal films, plastics and plastic composites. Metal alloys with a low thermal expansion coefficient, such as Invar ferronickel, can also be used. The layer 26 may also be formed of multiple metal layers including a thin sublayer disposed directly onto the insulating layer 24 which exhibits good adhesion strength as well as thermal conductivity and oxidation resistance. Examples of such materials are Enthone electroless nickel 422 and Shipley electroless copper 250. Next, an intermediate sublayer may be disposed on the sublayer for mechanical strength and thermal conductivity. Examples of materials for such intermediate sublayer include a copper film or 42 Lea Ronal electrolytic nickel PC3, electrolytic copper and Enthone electroless nickel 426. A thin outer sublayer may be disposed on the intermediate layer to provide superior abrasion resistance. Suitable materials include Enthone electroless nickel 426, Englehard electrolytic palladium nickel 80/20, TiN and chromium. The skin layer 26 may be a copper film in a copper film topped with nickel. Preferably, however, the skin layer 26 is a composite employing Ni particles 34 and a polymer matrix 36 and an overcoat of electroless nickel.

Hot thermoplastic resin 44 is injected from a source (not shown) into the mold cavity 16 via a sprue 46 and a gate 48. The sprue 46 may be coupled to a heated or cold inlet or runner, not shown.

In order to mold optical surfaces, the skin layer 26 which engages the stamper 20 may be provided with a mirror-surface finish such as a nickel plated copper composite for optical disk (OD) molding or a mirror-surface finish copper clad laminate for compact disk (CD) molding. Other alternatives for a CD mold insert 10 include a polyimide film sold under the Kapton, or high temperature thermoplastic laminates such as filled thermoplastic, should under the trademark ULTEM, optionally sandwiched between high gloss metal skins 26.

The present invention may use an insulating layer having a density variation across its thickness. More specifically, the insulating layer 24 may have a low density in the center region and a high density at each of the two surface regions. When the same material is used for each layer throughout the mold structure, the insulation properties of the insulating layer are due to the low density center region. That is, the center region has a lower thermal conductivity because of its porous nature. Also, because of the sameness of materials, the coefficient of thermal expansion (CTE) of the insulating layer will closely match the CTE of the adjacent core and skin layers. With the CTE of the adjacent layers closely matched, the potential of delamination is greatly reduced. Ceramic or metal materials are used when using the same material throughout the mold structure.

An insulating layer having a density variation across its thickness can be made by deposition of ceramics or metals using such deposition techniques as chemical vapor deposition, electroplating, and metal spraying, such as RF sputtering, electron beam deposition and plasma spraying. The low density area can be created by providing air bubbles or adding low density fillers such as hollow glass spheres, ceramics, metal oxides, bentonites, silica and the like in the center region.

In operation, the hot thermoplastic resin 44 is injected into the mold cavity 16, heat from the resin is absorbed through the stamper 20. Heat transfer, however, is regulated by the insert 12 which prevents quick cooling of the resin 44 and causes the stamper 20 to reheat. This results in a hot plastic surface at the interface between the stamper 20 and resin 44 for a short time period. The insert 12 and the stamper 20 cooperate to provide the desired surface quality to the finished part.

Passive heating of the hot thermoplastic need not be solely relied on. As set forth in U.S. Patent No. 5,176,839 incorporated herein by reference, alternative forms of active heating (e.g., oven, RF, etc.), heating may be utilized.

The invention promotes uniform flow and minimization of stress molecular orientation during disk formation. These factors contribute to achievement of uniform or nearly uniform birefringence. Which, in turn, results in suppression of optical distortion, and promotes uniform pits formation.

In a conventional mold, the radially divergent flow results in high polymeric orientation near the hub and reduced polymeric orientation near the outer radius. Without the invention, the various orientation effects at different radii become frozen in as the disk cools. The invention, however, has a number of beneficial effects. First, the insulated insert causes the stamper 20 to reheat whereby the flow front experiences less restriction. Accordingly, the force necessary to move the resin in the mold is reduced. Thus, the resin experiences reduced stress and has reduced orientation. Further, the reheat relaxes, anneals or smooths out any stress that is imparted, so that the orientation is rendered more uniform. This is especially helpful near the central hub where the resin initially enters the cavity, where the reheat effects are greatest, and where the force and hence stress and orientation are greatest. Thus, the invention is most effective to reduce non-uniformities in flow rates, stress and orientation where it is most needed. The invention also relaxes momentarily frozen-in orientation thereby further relieving stress; and birefringence variations are

for contacting the mold support.

5. The molding apparatus of claim 2 wherein the at least one outer skin layer comprises the plurality of sublayers.

6. The molding apparatus of claim 5 wherein one of said sublayers provides abrasion resistance to the molten thermoplastic material.

7. The molding apparatus of claim 5 wherein one of the plurality of sublayers provides adhesion strength for the outer skin layer to the insulating layer.

8. The molding apparatus of claim 5 wherein one of the plurality of sublayers provides structural integrity for the outer skin layer.

9. The molding apparatus of claim 1 wherein the insulating mold insert comprises:
a first layer of temperature-resistant material having low thermal conductivity;
a second layer deposited on said first layer, comprising a suspension of metal particles in a temperature-resistant material having low thermal conductivity.

10. The molding apparatus of claim 9 further including an outer metallic skin formed on the second layer.

11. The molding apparatus of claim 1 wherein the insulating layer comprises a material selected from the group consisting of thermoplastics, polyimides, polyamideimides and Kapton.

12. The molding apparatus of claim 11 wherein the insulating layer is about 2 to about 20 mils thick.

13. The molding apparatus of claim 1 wherein the optical media includes compact disks, optical disks and data disks.

14. The molding apparatus of claim 1, wherein the plastic is a material selected from the group consisting of polyamides, polyester, polyethylene terepthalate (PET), polybutadiene terepthalate (PBT), PBT with soft linkages formed of polycarbonate and methylene, polyether ketones, polyetherimides, polylactams, polypropylenes, polyethylenes, polystyrene, styrene acrylonitride, acrylonitrile butadiene terpolymers, polypropylene oxide (PPO)/polystyrenes, PPO/nylons and high impact polystyrene filled or unfilled and blends thereof.

15. The molding apparatus of claim 1, wherein the plastic is a material selected from the group consisting of filled or unfilled polycarbonates, polyesters, polyphenylene oxide, acrylonitrile butadiene styrene (ABS), styrene acrylonitrile, polyimide, blends and polymeric combinations thereof.

16. A method for molding an optical medium comprising the steps of: injecting a supply of thermoplastic material into the mold of claim 1 containing the mold insert; retaining the material in the mold for a time sufficient for the thermoplastic material to cool below the glass transition têmperature and ejecting the cool optical medium from the mold.

17. An optical medium formed by the method according to claim 16.

18. The optical medium according to claim 17 having substantially uniform birefringence as a result of molding.

19. A method for molding an optical medium comprising the steps of:
charging a molten thermoplastic materials into a molding apparatus having a stamper and an insert having a structure including a support for receiving the stamper; and an insulating mold insert removably located between the support and the stamper for slowing initial cooling of the thermoplastic during molding;
retaining the material in the mold for a time sufficient for the material to cool below its glass transition temperature; and
ejecting the article from the mold.

20. The method of claim 19 wherein the mold insert includes at least one outer skin layer disposed for contact with the stamper.

21. The method insert of claim 20 wherein the outer skin layer has a mirror finish.

22. The method of claim 19 wherein the insert comprises an insulating layer of temperature resistant material having a low thermal conductivity.

23. The molding apparatus of claim 21 wherein the insulating layer comprises a material selected from the group consisting of thermoplastics, polyimides, polyamideimides and Kapton.

24. The molding apparatus of claim 21 wherein the insulating layer is about 2 to about 20 mils thick.

25. The method of claim 19 wherein the insert comprises:
a first layer of temperature-resistant mate-

46. The mold insert of claim 29, wherein the plastic is a material selected from the group consisting of filled or unfilled polycarbonates, polyesters, polyphenylene oxide, acrylonitrile butadiene styrene (ABS), styrene acrylonitrile, polyimide, blends and polymeric combinations thereof.

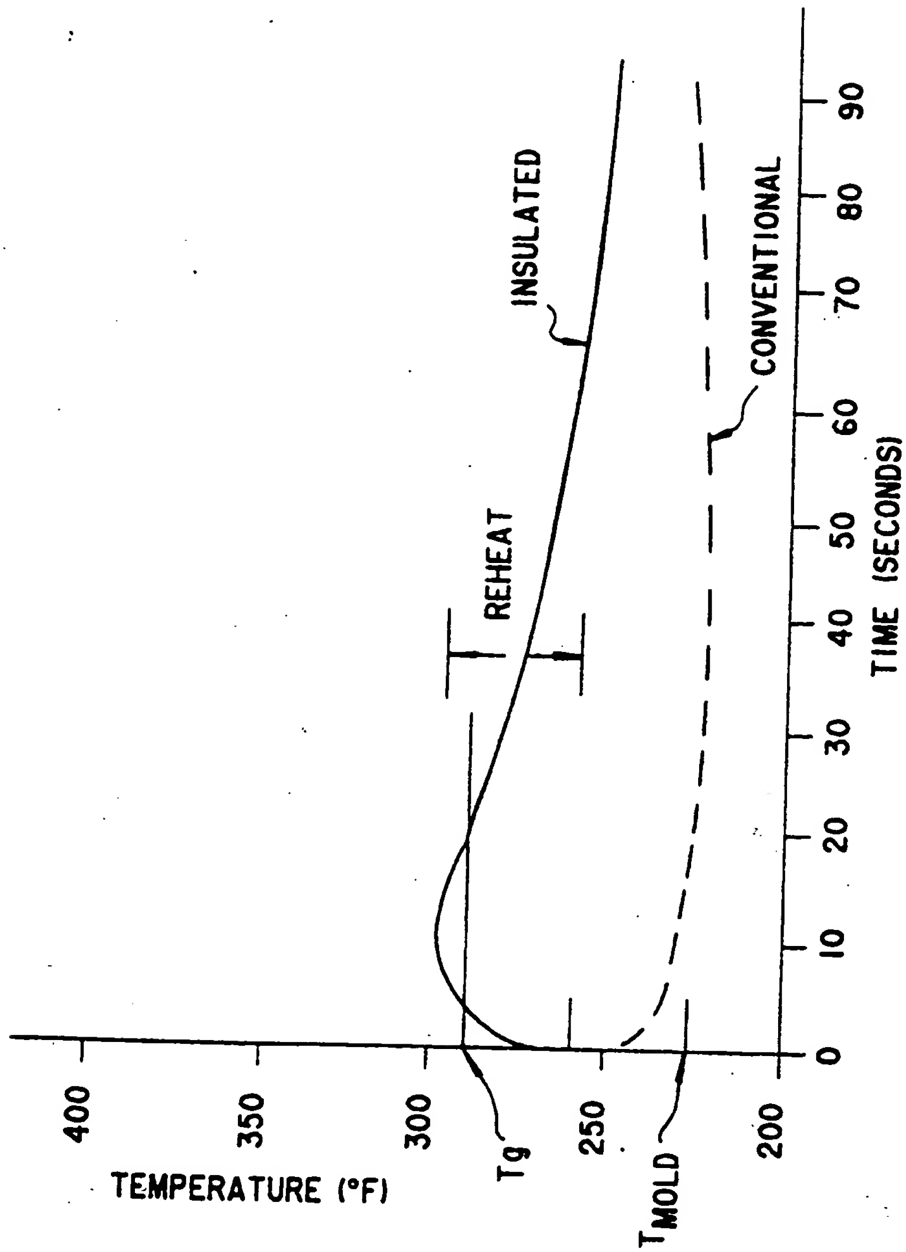
TEMPERATURE (°F)
400
350
300
250
200
Tg
TMOLD
TIME (SECONDS)
0
10
20
30
40
50
60
70
80
90
REHEAT
INSULATED
CONVENTIONAL

Fig.3